REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	May 17, 1999	3/1/98 - 2/28/99

4. TITLE AND SUBTITLE

"Observations of Planet Crossing Asteroids"

5. FUNDING NUMBERS

NAS 5-4524

6. AUTHORS

David J. Tholen

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

University of Hawaii Institute for Astronomy
2680 Woodlawn Drive
Honolulu, HI 96822

8. PERFORMING ORGANIZATION REPORT NUMBER

6-54760

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

NASA Headquarters
Washington, DC 20546

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

NAG 5-4524

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

DISTRIBUTION STATEMENT A
Approved for Public Release
Distribution Unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This grant funds the investigation of the Solar System's planet-crossing asteroid population, principally the near-Earth and trans-Neptunian objects, but also the Centaurs. Investigations include colorimetry at both visible and near-infrared wavelengths, light curve photometry, astrometry, and a pilot project fo find near-Earth objects with small aphelion distances, which requires observations at small solar elongations.

14. SUBJECT TERMS

near-Earth, trans-Neptunian, Centaurs, photometry, astrometry

15. NUMBER OF PAGES

7 pages

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT

University of Hawai'i at Mānoa

Institute for Astronomy
2680 Woodlawn Drive • Honolulu, Hawai'i 96822

10 May 1999

Dr. Thomas H. Morgan
Discipline Scientist
Planetary Astronomy Program
Code SR
NASA Headquarters
Washington, DC 20546

SUBJECT: Annual Progress Report, NAG 5-4524

Dear Dr. Morgan,

Enclosed is the annual progress report for the above referenced grant entitled, "Observations of Planet Crossing Asteroids," under the direction of Dr. David J. Tholen, Principal Investigator. This report covers the period 1 March 1998 to 28 February 1999. This is the first year of a three-year award.

We herewith request that the additional recommended second year funding be obligated and released to the University of Hawaii. Attached is the second year budget.

If you have any questions, please contact Chris Kaukali, Administrative Officer, at 808-956-7271, or email, kaukali@ifa.hawaii.edu.

Please ensure that all correspondence to this request is directed to Mr. Marvin S. Enokawa, Director, Office of Research Services, 2530 Dole Street, Sakamaki Hall D-200, Honolulu, Hawaii, 96822.

Sincerely,

David J. Tholen
Principal Investigator

ENDORSEMENT:

Marvin S. Enokawa
Director
Office of Research Services

xc: Theresa Curtis, 210.G
NASA CASI
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David Tholen

PROGRESS REPORT

NASA Grant NAG5-4524
Observations of Planet Crossing Asteroids
David J. Tholen, P.I.

Dates
1998 March 1 to 1999 February 28

Location
University of Hawaii
Institute for Astronomy
2680 Woodlawn Drive
Honolulu, HI 96822

Personnel
This grant provided half-time salary support for one graduate student, Robert J. Whiteley, and research support for both Mr. Whiteley and the P.I.

Goals
This grant funds the investigation of the Solar System's planet-crossing asteroid population, principally the near-Earth and trans-Neptunian objects, but also the Centaurs. Investigations include colorimetry at both visible and near-infrared wavelengths, lightcurve photometry, astrometry, and a pilot project to find near-Earth objects with small aphelion distances, which requires observations at small solar elongations.

Photometry
With regard to the near-Earth objects, new observations were acquired for 4 Atens, 29 Apollos, and 17 Amors:

(433) Eros
(1036) Ganymed
(1627) Ivar
(1866) Sisyphus
(1980) Tezcatlipoca
(2102) Tantalus
(3352) McAuliffe
(4183) Cuno
(5751) Zao
(6037) 1988 EG
(7358) 1995 YA3
(7888) 1993 UC
(7889) 1994 LX
(7977) 1977 QQ5
(8201) 1994 AH2
(10115) 1992 SK
(10302) 1989 ML
1989 UR
1991 VE
1998 DV9
1998 EC3
1998 FX2
1998 FM5
1998 HE3
1998 HD14
1998 KU2
1998 KY26
1998 MQ
1998 ME3
1998 PG
1998 QA1
1998 QC1
1998 QR15
1998 QK28
1998 QS52
1998 UT18
1998 VO
1998 VR
1998 VD32
1998 VO33
1998 WM
1998 WT
1998 WZ1
1998 WB2
1998 WZ6
1998 XM4
1998 XC9
1998 XS16
1998 YB8
1999 CF9

Most of these observations are being incorporated into Mr. Whiteley's doctoral dissertation; the current target date for completion is the end of 1999. Selected observations will be published separately, including those for 1998 KY26, which have been incorporated into a paper about both the optical and radar observations of this rapidly rotating object (period of 10.7 *minutes*!), and those for 1989 ML, one of the potential targets for the MUSES-C sample return mission.

With regard to the trans-Neptunian objects, observations were acquired for 20 objects:

1993 FW	1995 YY3	1997 CT29
1993 SB	1996 TL66	1997 CU29
1993 SC	1996 TO66	1997 QJ4
1994 JR1	1996 TQ66	1998 FS144
1994 TB	1996 TS66	1998 WH24
1995 HM5	1997 CQ29	1998 XY95
1995 QY9	1997 CS29	

Some of these observations benefited from the simultaneous scheduling of the UH 2.24-m telescope and UKIRT, thereby permitting V–J colors to be measured without the need to estimate some correction for lightcurve and phase function differences. Other observations were made in collaboration with M. A. Barucci at ESO's New Technology Telescope.

Observations were also made of the Centaurs (5145) Pholus, (10199) 1997 CU26, and (10370) 1995 DW2; the Jupiter crosser 1998 QJ1; and Mars crossers (9969) 1992 KD, 1998 WU24, and 1998 YF27. The last two have particularly unusual orbits; 1998 WU24 has a semimajor axis of 15 AU but an eccentricity of 0.9, which makes it cross the orbits of Uranus, Saturn, Jupiter, and Mars, while 1998 WF27 has the twentieth highest inclination (46.3 deg) among the known asteroids. 1992 KD is the target of the Deep Space 1 technology demonstration mission.

Photometry was also performed on a dozen bright stars (rough visual magnitude 4) to standardize them in the Eight-Color Asteroid System to support the AMICA instrument on the MUSES-C spacecraft, which will visit either (4660) Nereus or (10302) 1989 ML.

Discovery

During the year covered by this report, we've had two runs allocated to continue our pilot project to find asteroids with small aphelion distances. The weather cooperated for nine quarter nights of observations. No new NEOs were discovered in an area of not quite 20 square degrees.

For one of our runs to search for asteroids at small solar elongations, we were awarded whole nights. We used the middle of the nights, when small solar elongations were unavailable, to improve on the search for distant satellites of Uranus and Neptune that led to the discovery of two distant Uranian satellites in 1997 by Gladman *et al.* (IAU Circular 6764). We recovered both of the 1997 discoveries and discovered a third object sharing Uranus' motion. Continued observation of this new object revealed motion slightly too fast to be in elliptical motion around Uranus, but entirely consistent with elliptical motion around the Sun, thus this object, which received the designation 1998 QM107, appears to be the ninth Centaur object known. Astrometry was obtained through the end of November, and the three-month arc yielded an orbit

solution showing a semimajor axis of 20.1 AU, an eccentricity of 0.14, and an inclination of 9 deg, which places it in an orbit slightly more eccentric and inclined than Uranus', but at nearly the same mean distance from the Sun. We intend to investigate the dynamical behavior of this object once a better orbit can be computed using recovery observations from after solar conjunction. [News flash: only hours after this report was written, the word from C. Trujillo is that he successfully recovered the object during an observing run to perform follow-up astrometry of newly discovered Kuiper belt objects.]

Astrometry

Astrometric observations of NEOs and TNOs were acquired and reported for several objects. Of particular significance are the observations of 1998 KY26, which helped to refine the orbit solution enough to permit successful radar observations of the object, which turned out to be the fastest spinning asteroid currently known and an exciting development. We also extended the observational arcs on the potentially hazardous asteroids 1997 QK1 and 1998 DV9 (two of our own small solar elongation discoveries) by three and two months, respectively, over the last observation obtained by any other observatory, which required reaching a visual magnitude of 25 for 1997 QK1 and 23 at a solar elongation of 60 deg for 1998 DV9. Another important target of our astrometric efforts was 1989 ML, in support of the MUSES-C sample return mission.

Software Development

The most significant software development of the past year is an orbit/ephemeris capability for objects with only two available astrometric observations. We became acutely aware of the need for such a capability during our 1998 February run to find NEOs at small solar elongations. Because of a camera failure, we lost a night and were forced to attempt a recovery one night later with a CCD providing a much smaller field. The ephemeris available on the Minor Planet Center's NEO confirmation web page was inadequate in the sense that if the object was not found at the predicted location, it would not tell you the next best place to look for it. As a result, we wasted time looking in directions that we now know corresponded to hyperbolic or retrograde orbit solutions. The new software maps out the region of sky where elliptical and prograde orbit solutions are possible. It accomplishes this feat by varying the length of the topocentric position vector that corresponds to the midpoint of the two observations, and by varying the angle at which the velocity vector that connects the two observations is projected onto the plane of the sky. For each pair of topocentric position and velocity vectors, a set of heliocentric orbital elements is derived. Parabolic, hyperbolic, and retrograde orbit solutions are rejected, and the ephemerides from the surviving sets of orbital elements are used to plot the allowable region of sky where the object must lie. Not only does this program tell us where *not* to waste time trying to recover an object, it tells us whether it is feasible to cover the allowable region of sky with the field of view available to us. The size of the allowable region grows with time at a rate that depends on the speed of the object and how large the extrapolation in time is relative to the interval spanned by the observations (which tend to be very short for objects found at small solar elongations, due to the small amount of time they are above the horizon while the sky is dark). We expect this tool to be indispensable when future objects are discovered. Although we haven't found any new NEOs since this software development was completed, the program has been used to determine the recoverability (and also to recover) one of the recent trans-Neptunian discoveries as well as a main-belt object. Copies of the executable have been provided to Petr Pravec (Ondrejov Observatory in the Czech Republic), Ilan Milanus (Wise Observatory in

Israel), and Roy Tucker (Goodricke-Pigott Observatory near Tucson) so far, and Steve Larson/Tim Spahr (Catalina Sky Survey) have expressed interest in the program as well.

Development was completed on software to extract subsets of the USNO astrometric reference catalog for purposes of positional measurement of Solar System objects on our CCD images. We also received and installed the latest version (A2.0) of the catalog. A graphical interface was also developed to display the extracted catalog data alongside our CCD images. Preliminary work was done to automatically associate catalog entries with sources in the CCD images. Our goal is to develop a processing pipeline that can take CCD images as input and produce a list of astrometry for all moving objects as output. Currently we ignore slow-moving objects, which have a very high probability of being main-belt asteroids, because we don't have the manpower to handle the dozens of moving objects we find manually.

Orbit Determinations

The P.I. has been assisting D. Jewitt and his thesis student C. Trujillo with their discoveries of trans-Neptunian objects by performing orbit solutions and computing ephemerides for recovery and physical observation purposes. Over the last year, this effort has involved approximately three dozen objects.

Perturbed orbit solutions were performed for our own NEO discoveries, 1997 QK1 and 1998 DV9, as new observations came in. Also, in response to questions raised by local media during the 1997 XF11 affair, orbit solutions were performed for this object to verify the close approach distance in 2037 publicized by the Minor Planet Center.

An improved orbit for 1989 ML, a potential target of the MUSES-C spacecraft mission, was computed following the acquisition of new astrometry during a recent observing run, and provided to scientists involved in the MUSES-C project.

Publications

The following list includes manuscripts soon to be submitted for publication that describe the results of observations funded by the grant, related manuscripts that have already been submitted for publication during the reporting period, and papers that were published during the reporting period, but based on observation funded by the predecessor grant.

DAVIES, J. K., S. GREEN, N. MCBRIDE, E. MUZZERALL, D. J. THOLEN, R. J. WHITELEY, M. J. FOSTER, AND J. K. HILLIER 1999. Visible and infrared photometry of Kuiper belt objects. (to be submitted).

DAVIES, J. K., D. J. THOLEN, R. J. WHITELEY, S. F. GREEN, M. J. FOSTER, N. MCBRIDE, T. H. KERR, AND E. MUZZERALL 1999. The lightcurve and colors of unusual minor planet 1998 WU24. (to be submitted).

BARUCCI, M. A., A. DORESSOUNDIRAM, D. THOLEN, M. FULCHIGNONI, AND M. LAZZARIN 1999. Spectrophotometric observations of Edgeworth-Kuiper belt objects. *Icarus* (submitted).

HARRIS, A. W., J. W. YOUNG, E. L. G. BOWELL, AND D. J. THOLEN 1999. Asteroid lightcurve observations from 1981-1983. *Icarus* (submitted).

OSTRO, S. J., P. PRAVEC, L. A. M. BENNER, R. S. HUDSON, L. SAROUNOVÁ, M. D. HICKS, D. L. RABINOWITZ, J. V. SCOTTI, D. J. THOLEN, M. WOLF, R. F. JURGENS, M. L. THOMAS, J. D. GIORGINI, P. W. CHODAS, D. K. YEOMANS, R. ROSE, R. FRYE, K. D. ROSEMA, R. WINKLER, AND M. A. SLADE 1999. Radar and optical observations of asteroid 1998 KY26. *Nature* (submitted).

WHITELEY, R. J., AND D. J. THOLEN 1998. CCD search for Lagrangian asteroids of the Earth-Sun system. *Icarus* **136,** 154-167.

CRUIKSHANK, D. P., T. L. ROUSH, M. J. BARTHOLOMEW, T. R. GEBALLE, Y. J. PENDLETON, S. M. WHITE, J. F. BELL III, J. K. DAVIES, T. C. OWEN, C. DEBERGH, D. J. THOLEN, M. P. BERNSTEIN, R. H. BROWN, K. A. TRYKA, AND C. M. DALLE ORE 1998. The composition of Centaur 5145 Pholus. *Icarus* **135,** 389-407.

Astrometry and/or orbit computations for minor planets and/or comets have been published in the following *Minor Planet Circulars* and *Supplements*):

MPC 34404 (1999)	MPS 1979 (1998)	MPS 565 (1998)
MPS 4529 (1999)	MPC 31871 (1998)	MPC 31196 (1998)
MPS 4477 (1999)	MPS 1494 (1998)	MPS 464 (1998)
MPS 4463 (1999)	MPC 31647 (1998)	MPS 453 (1998)
MPC 34105 (1999)	MPS 926 (1998)	MPC 31061 (1998)
MPS 4095 (1999)	MPC 31340 (1998)	MPS 287 (1998)
MPC 32395 (1998)	MPC 31339 (1998)	MPS 286 (1998)

Critical astrometric observations have been published on the following *Minor Planet Electronic Circulars*:

MPEC 1998-X23 (1998)	1998 QM107
MPEC 1998-E18 (1998)	1998 DV9

RTOP# _____
GRANT/CONTRACT NO. _____

YEARLY BUDGET SUMMARY

SECOND YEAR BUDGET AND PERSONNEL SUMMARY BREAKDOWN

TITLE: Observations of Planet Crossing Asteroids

PRINCIPAL INVESTIGATOR & INSTITUTION: University of Hawaii, Institute for Astronomy

SUMMARY OF SECOND YEAR PROPOSED COSTS: (nearest $K)

1.	SALARIES AND WAGES	$ 23,258
2.	SUPPLIES AND MATERIALS	$ 1,439
3.	EQUIPMENT PURCHASES	$ 5,000
4.	COMPUTER TIME (paid with PI funds)	$ 2,496
5.	SERVICES	$
6.	PUBLICATIONS AND COMMUNICATIONS	$ 1,600
7.	TRAVEL* (see attached budget)	$ 12,548
8.	OTHER (INCLUDING BENEFITS AND OVERHEAD)..	$ 16,659
9.	SUBTOTAL SECOND YEAR BUDGET	$ 63,000
10.	INSTITUTIONAL CONTRIBUTIONS	$
11.	CARRYOVER FROM PREVIOUS AWARD	$
12.	TOTAL BUDGET REQUESTED FOR ALL YEARS NEW FUNDS REQUESTED FROM NASA (LINES 9, 10, 11)	$ 63,000

****

SUMMARY OF STAFFING REQUEST (NEAREST $K, NEAREST 0.1 WORKYEAR)

1.	SENIOR PERSONNEL (Tholen)	.1 wy	$
2.	TECHNICAL SUPPORT (GIVE NUMBER)	wy	$
3.	OTHER (Graduate Student)	.6 wy	$ 23,258
4.	TOTALS	.7 wy	$ 23,258

* Provide names of travelers, dates, and destinations for each year of support requested.

SUMMARY OF FUNDING REQUEST (NEAREST 0.1 WORKYEAR, NEAREST $0.1K)

TASK SHORT TITLE	SENIOR PERSONNEL	TECHNICAL SUPPORT	OTHER COSTS
1.			
2.			
3.			
4.			

PROPOSED BUDGET FOR
"Observations of Planet Crossing Aste:"
David Tholen - Principal Investigator
36 Months

Year 2 (01/01/99-12/31/99)

							BUDGET	SUBJ TO MTDC	SUBJ TO ARS	NOT SU TO MT
SALARIES & WAGES:										
Graduate Student (50% FTE)	12 months	x	$1,640	=	$19,680					
Graduate Student (Overload)	1 month	x	$3,578	=	$3,578					
			Total Salaries and Wages:				$23,258	$23,258	$23,258	
SUPPLIES & MATERIALS:							$1,439	$1,439	$1,439	
Computer supplies, software, storage media										
EQUIPMENT:										
18 GB Disk Drive, Exabyte Tape Drive					$5,000		$5,000			$5,0
COMPUTER SERVICES:										
Computer Division (Student)	12 months	@	$2,496 /12		$2,496		$2,496	$2,496		
PUBLICATIONS & COMMUNICATIONS:										
Page Charges	10 pages	@	$130 / pg	=	$1,300					
Communications (tolls, telemail, facsimile, etc.)					$300					
			Total Publications & Communications:				$1,600	$1,600	$1,600	
TRAVEL - DOMESTIC:										
12 Trips to Mauna Kea (UH 2.2-M)										
Airfare					$82					$3,9
Hale Pohaku Accommodations	4 days	@	$82 / day	=	$328					
Ground Transportation & Misc.	4 days	@	$25 / day	=	$100					
	2 persons	x	6	x	$510	= $6,120				
TRAVEL - FOREIGN:										
DPS Meeting '99 (Europe)										
Airfare (Honolulu-Europe-Honolulu)					$1,600					
Conference Fees					$140					
Per Diem	5 days	@	$175 / day	=	$875					
Ground Transportation & Misc.	5 days	@	$45 / day	=	$225					
	1 person	x	1	x	$2,840	= $2,840				
ACM Meeting (Italy)										
Airfare (Honolulu-Milan-Honolulu)					$1,600					
Per Diem	7 days	@	$234 / day	=	$1,638					
Ground Transportation & Misc.	7 days	@	$45 / day	=	$350					
	1 person	x	1	x	$3,588	= $3,588				
			Total Travel-Foreign & Domestic:				$12,548	$8,612	$8,612	
OTHER:										
Fringe Benefits, Student (7.1%)	12 months	@	$1,640		x 7.1%	= $1,397		$1,397	$1,397	
Administrative Support Services										
Admin/Prof	9.49%	x	$18,153	=	$1,723					
Clerical	9.49%	x	$18,153	=	$1,723					
			Total Administrative Support Services:			$3,445		$3,445		
			Total Other Direct Costs:				$4,842			
			TOTAL DIRECT COSTS:				$51,183	$42,247	$36,306	$8,9
INDIRECT COSTS:			27.97% of Modified Total Direct Cost (MTDC)				$11,817			
			YEAR 2 TOTAL COST:				**$63,000**			